

Being Realistic about Geothermal Potential

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Reality #1: geothermal water is a relatively low-enthalpy, low-value product compared to oil and gas

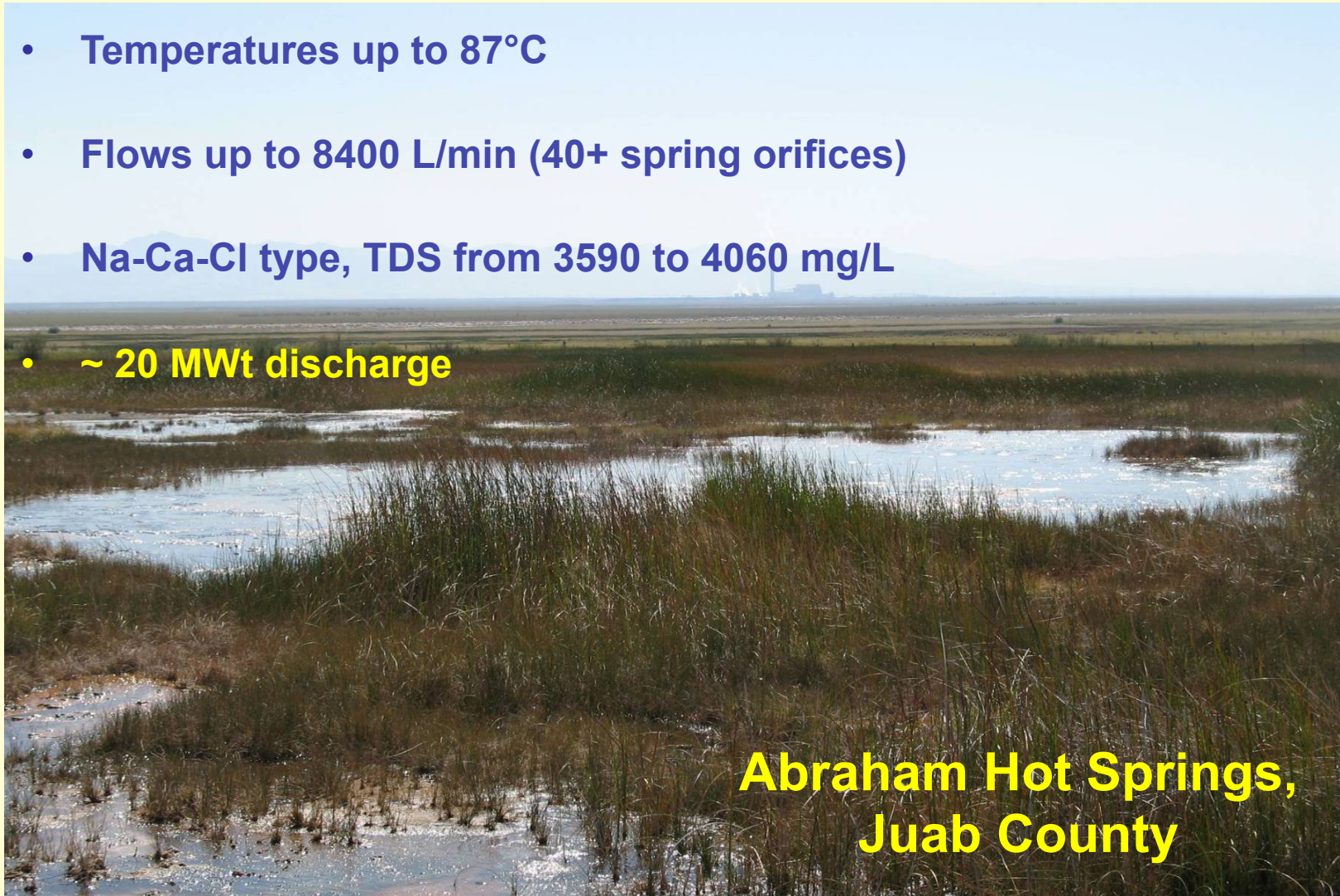
Energy Source	"Good" Well Flow Rate	Energy Flow Rate	Value (\$/day per well)
<i>Geothermal</i>	100 kg/s	100 MW _{th} , 10 MW _e	\$24k @ 10c/kWh
<i>Ground Water</i>	2000 gpm (130 kg/s)	pump needed	\$3k @ \$1/1000 gal
<i>Oil</i>	5,000 bbl/d (16 kg/s)	320 MW _{th}	\$400k @ \$80/bbl
<i>Natural Gas</i>	20,000 mcf/d	250 MW _{th}	\$80k @ \$4/mcf

Geothermal wells require great permeability (high flow rates); new technologies such as horizontal legs and multi-stage “frac” completions are now common in oil and gas developments for enhancing flow rate, but the extra costs of these technologies are “challenging” for geothermal developments in today’s power market

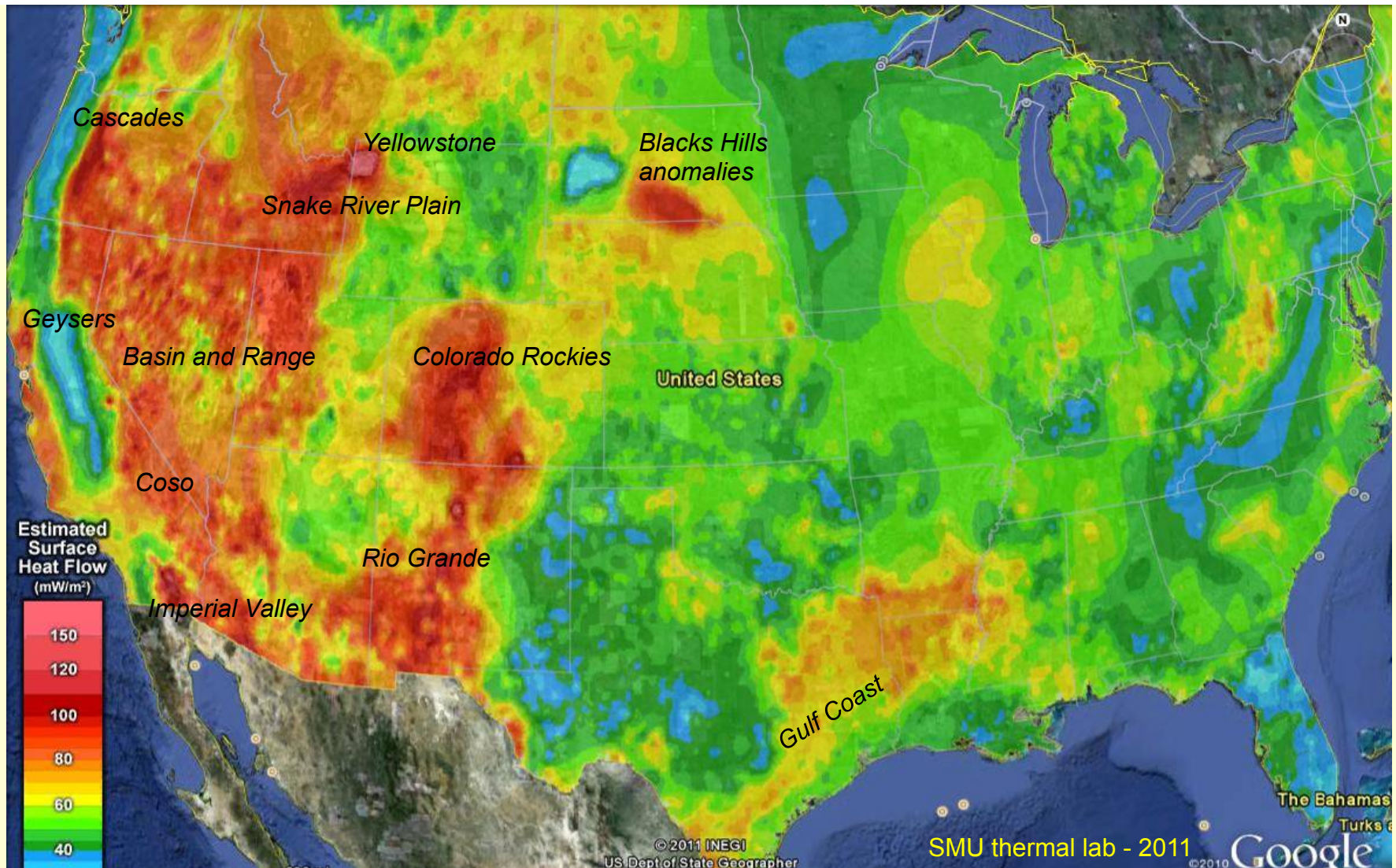
Reality #2: the hydrothermal upflow zones associated with hot springs in the Western U.S. tend to be small in area (< a few square miles). Most geothermal power developments tapping these have production wells within 1 - 2 sq miles, and they generate ~ 10 – 50 MWe.

We need larger scale developments!

- Temperatures up to 87°C
- Flows up to 8400 L/min (40+ spring orifices)
- Na-Ca-Cl type, TDS from 3590 to 4060 mg/L
- ~ 20 MWt discharge



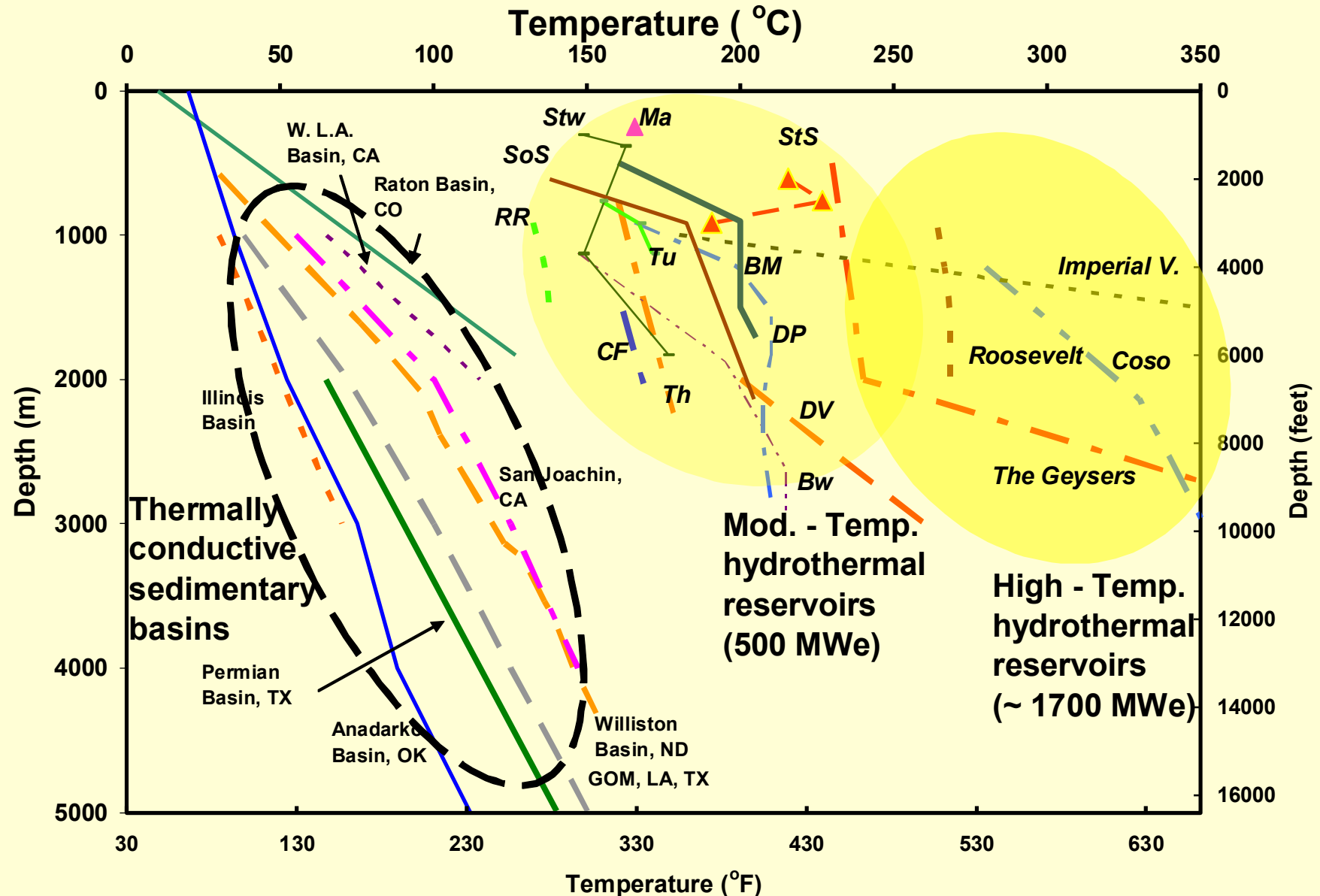
**Abraham Hot Springs,
Juab County**



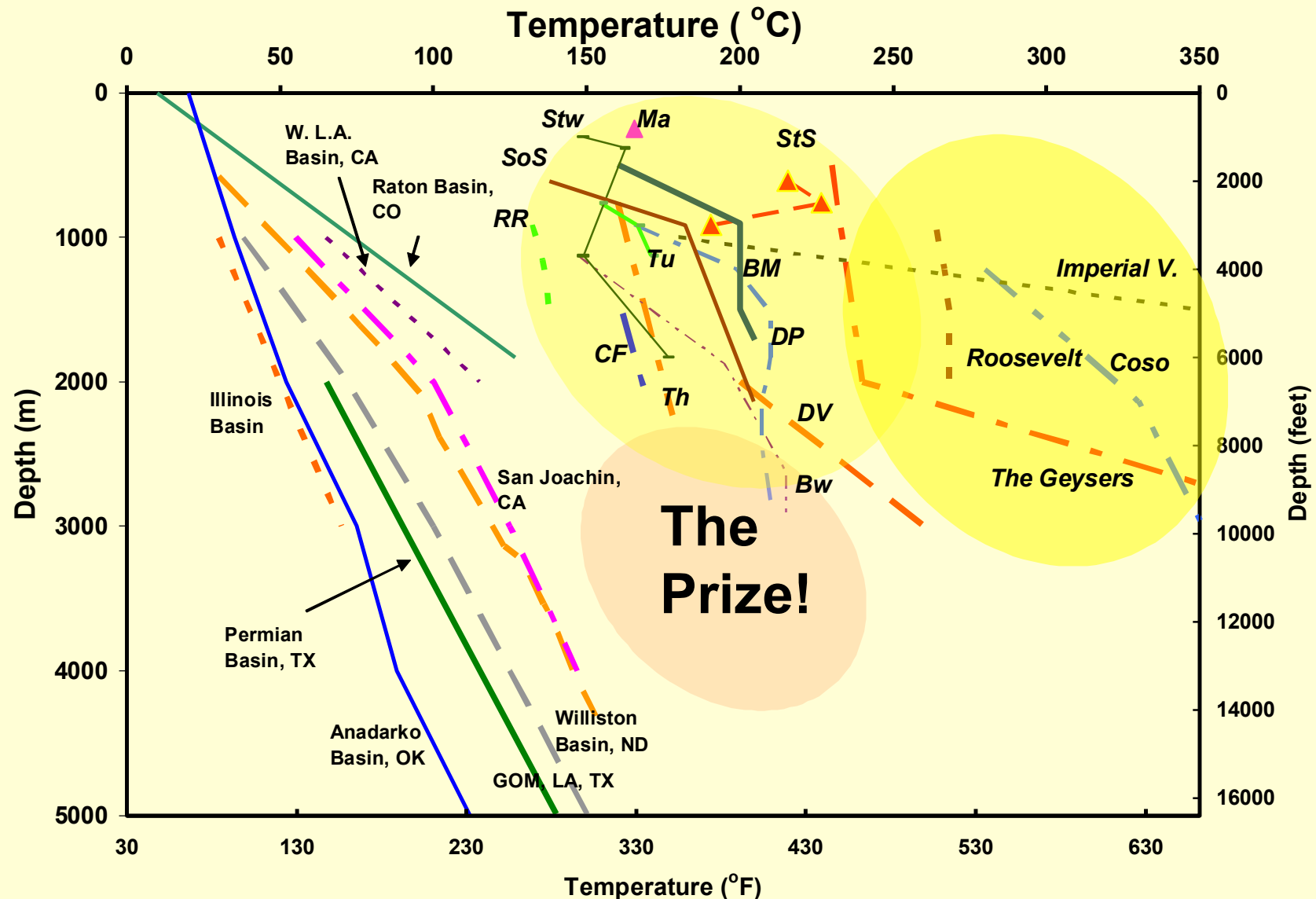
Reality #3: we have $\sim 10^6$ km² of high heat flow terrain in the west (> 90 mW/m²) and a major fraction of this is in form of sedimentary successions with the potential for stratigraphic reservoirs where the temperatures are $\sim 200^\circ\text{C}$ (400°F) @ $> 3 - 5$ km (10,000 – 16,000 ft)

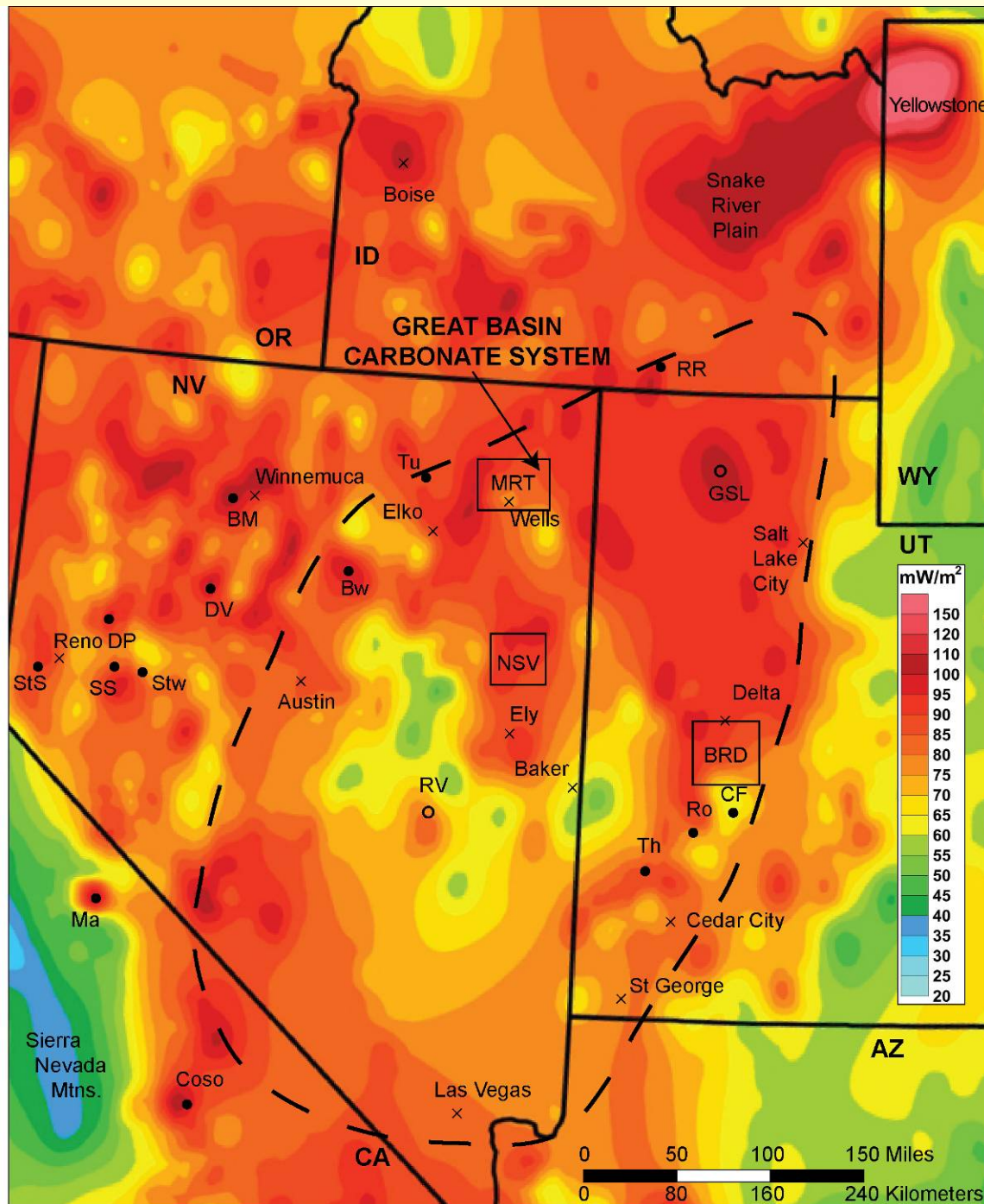
High heat flow basins are where we will find the “undiscovered” geothermal elephants!

Where is the next GWe of geothermal power in the U.S. going to be generated?
 (MWe in brackets are “running capacity” compilations from GEA website)



The Prize: Paleozoic sedimentary units beneath high-heat flow basins in the Great Basin where temperatures are $> 150^{\circ}\text{C}$ (300°F), and there is natural stratigraphic permeability. The prospective area is large! ($\sim 1000 \times 500 \text{ km}^2$). However the wells are deeper than geothermal industry is comfortable with.





Great Basin Carbonate System superimposed on regional heat flow map of western U.S. (from Blackwell et al., 2011). The Paleozoic carbonate units are known to have aquifer properties, which if hot enough may also be geothermal reservoirs.

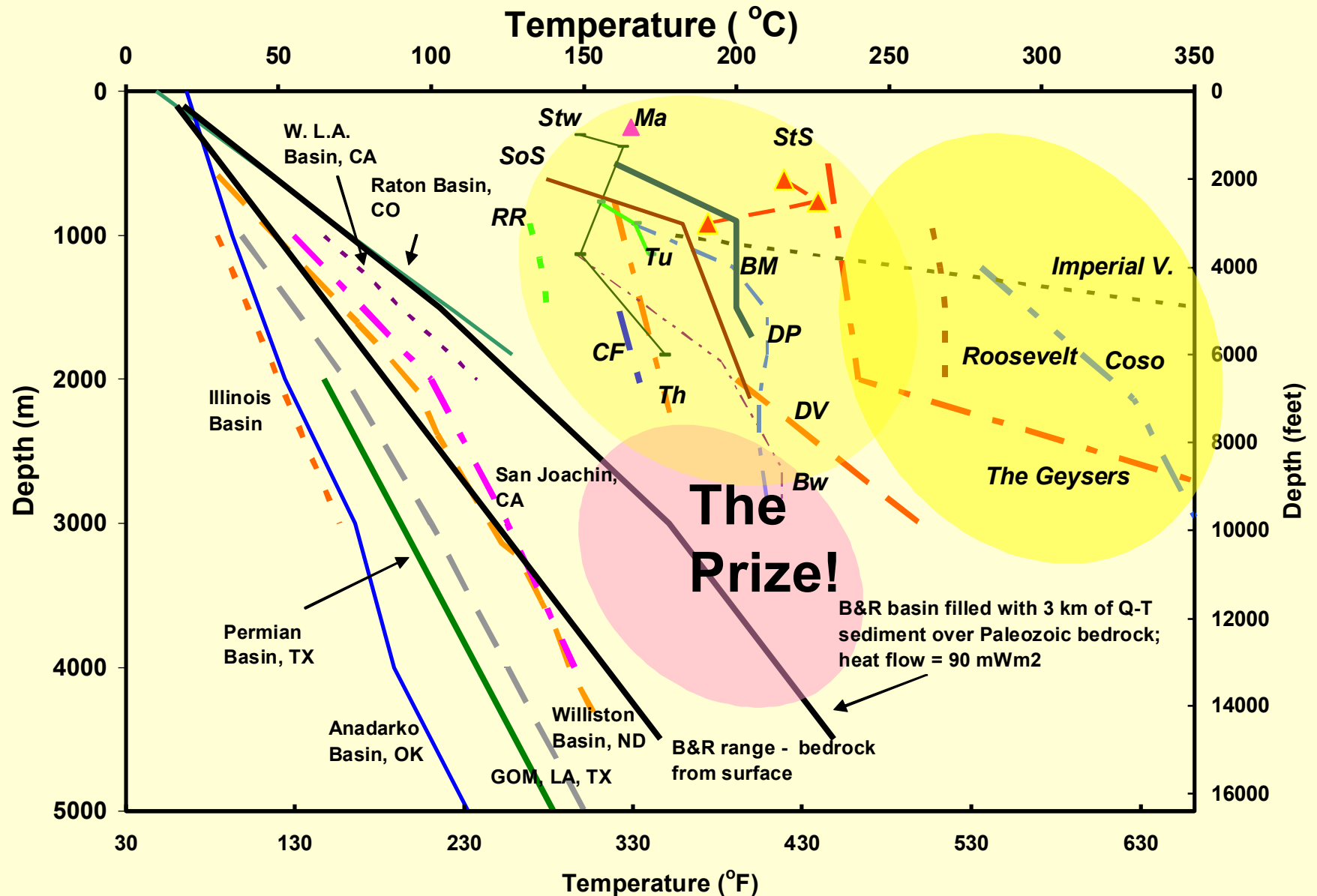
Locations of geothermal power plants (dots) and the three basins (rectangles) discussed in this presentation:

BRD = Black Rock Desert, UT

NSV = Nth Steptoe Valley, NV

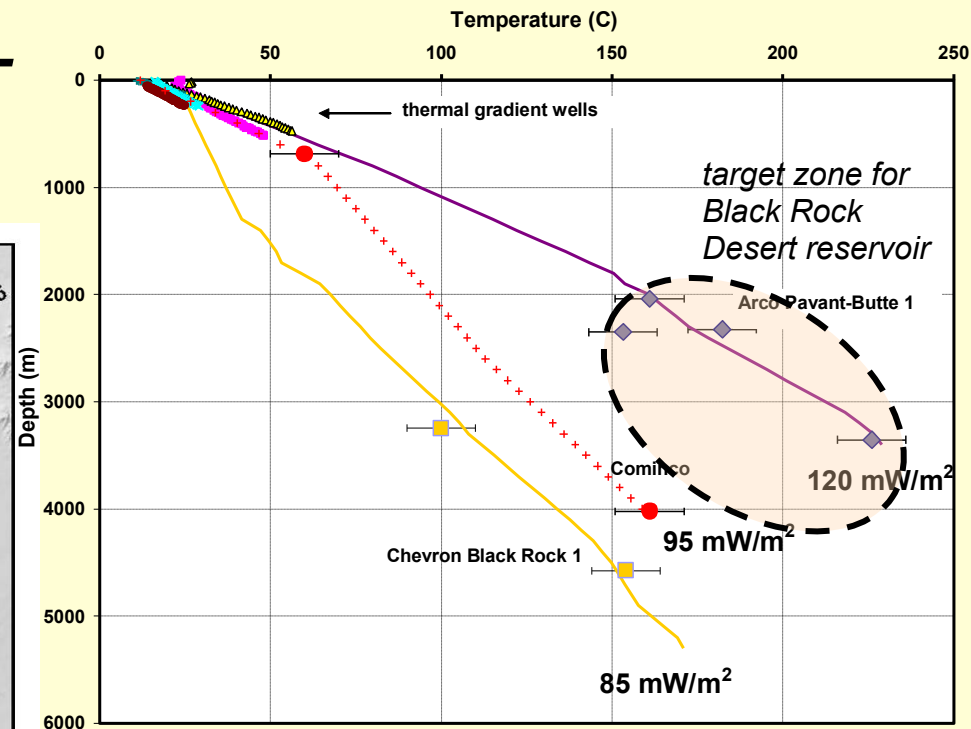
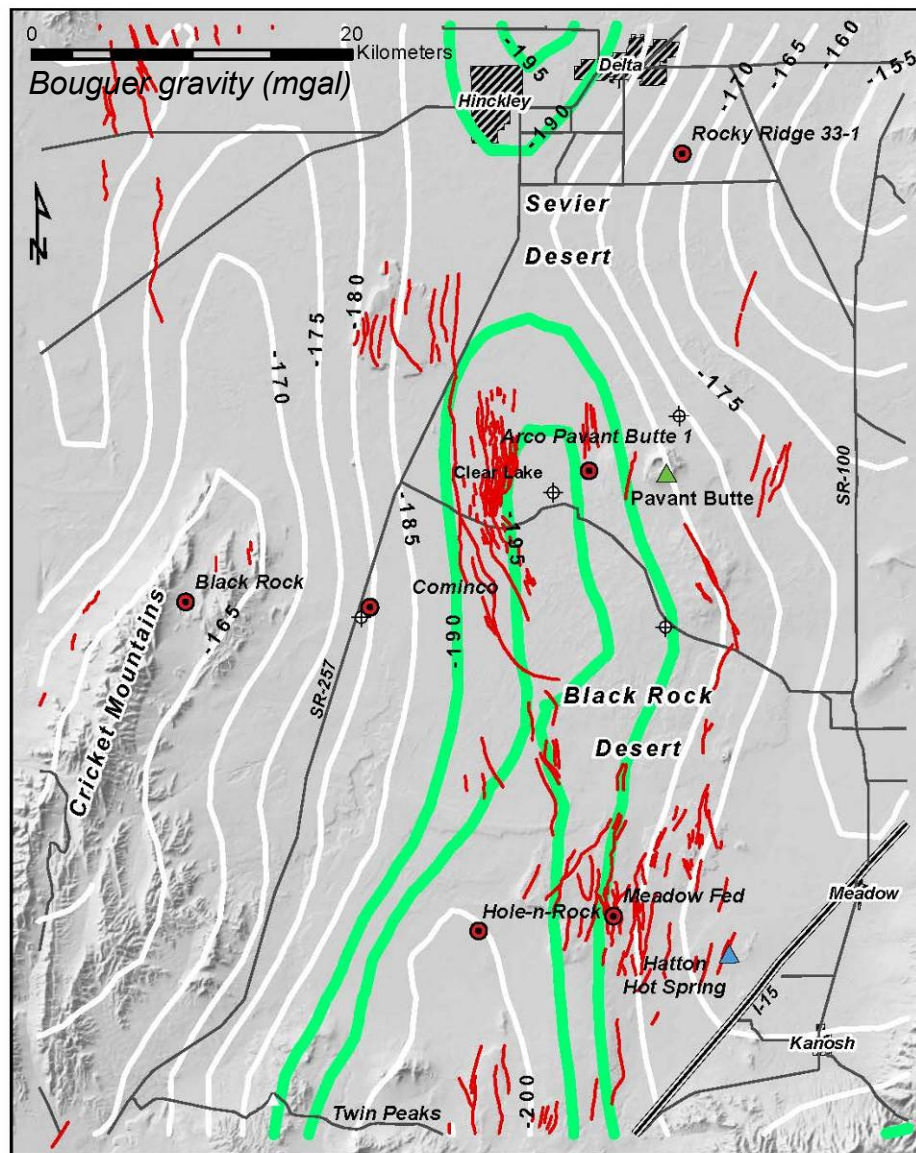
MRT = Mary's River – Toano basins, NV

Reality #4: The hottest conditions at depth in the Great Basin are beneath the basins (due to thermal conductivity effects). Until now, the exploration focus has been locating hydrothermal upflows within faults bounding the ranges.



Black Rock Desert, Central UT

Green contours represent > 2 km of basin fill



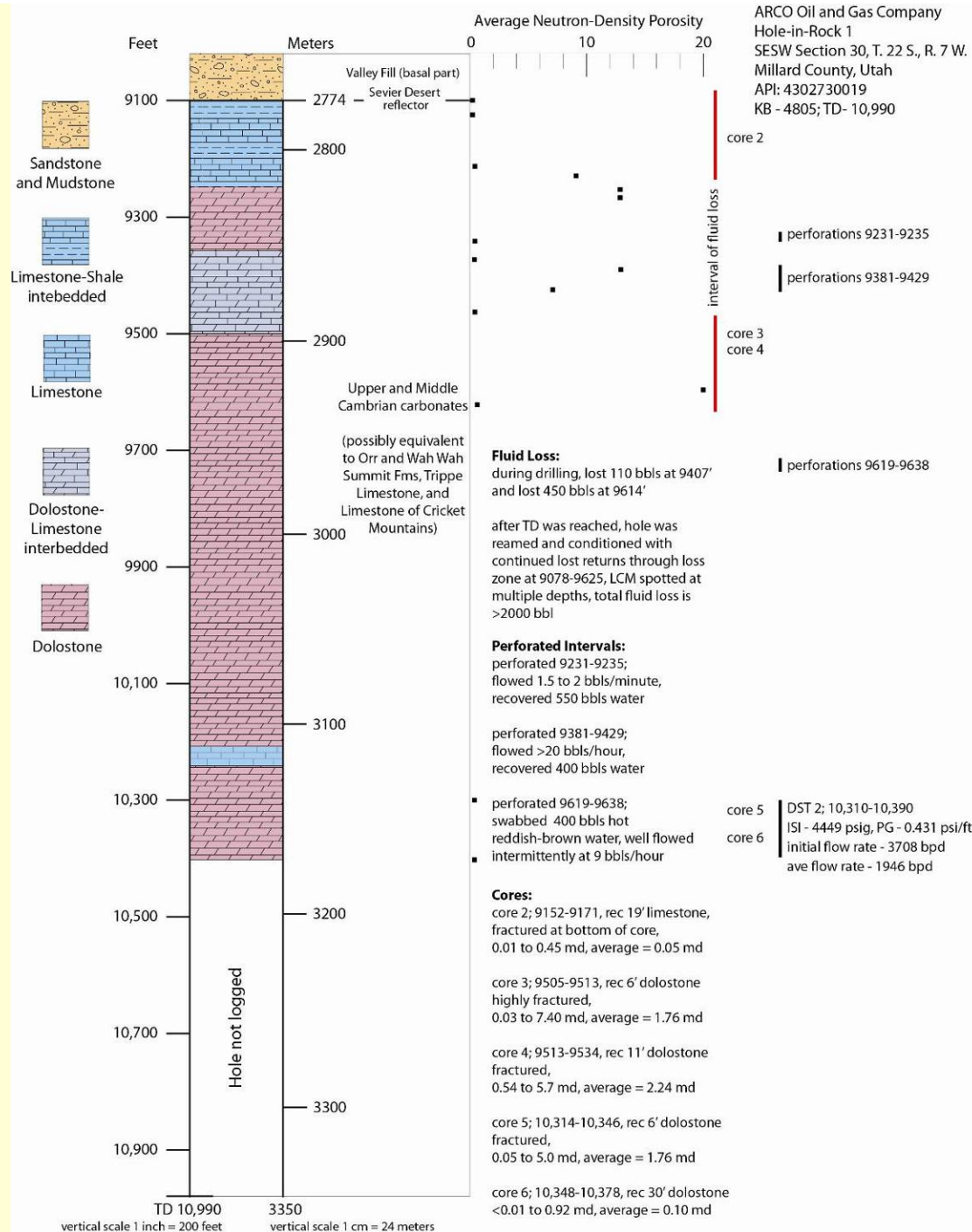
Preliminary Indications:

The Pavant Butte – Clear Lake area may have the highest temperatures (> 200°C @ > 3 km depth) in this basin; rest of basin may be ~ 170 – 190°C at < 4 km depth. Area ~ 500 km² – the resource potential is large!

What do stratigraphic reservoirs look like?

Arco's "Hole-n-Rock" oil exploration well in southern Black Rock Desert, UT, encountered large drilling fluid losses once in the carbonate units below 2774 m depth. These loss zones and drilling problems precluded reliable temperature measurements in the carbonate units.

New temperature gradient wells indicate a near-surface gradient of about 60°C/km and a temperature at 3 - 4 km of 170 – 200°C (preliminary data!)

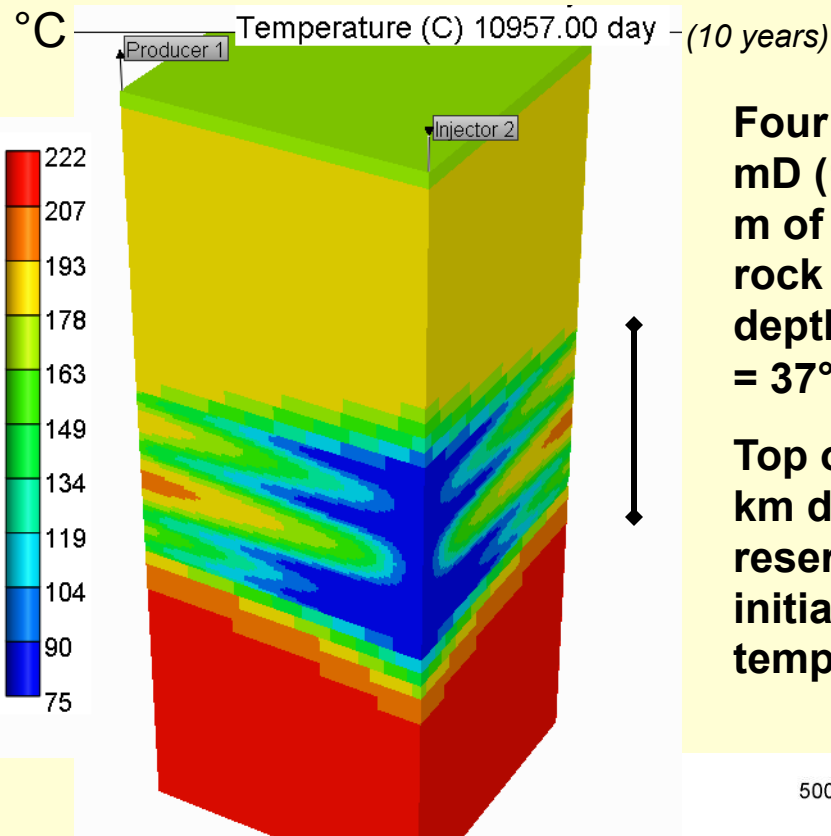


In many of these basins, access is easy, and even the sage brush has trouble surviving

**Northern Black Rock
Desert, near Delta**

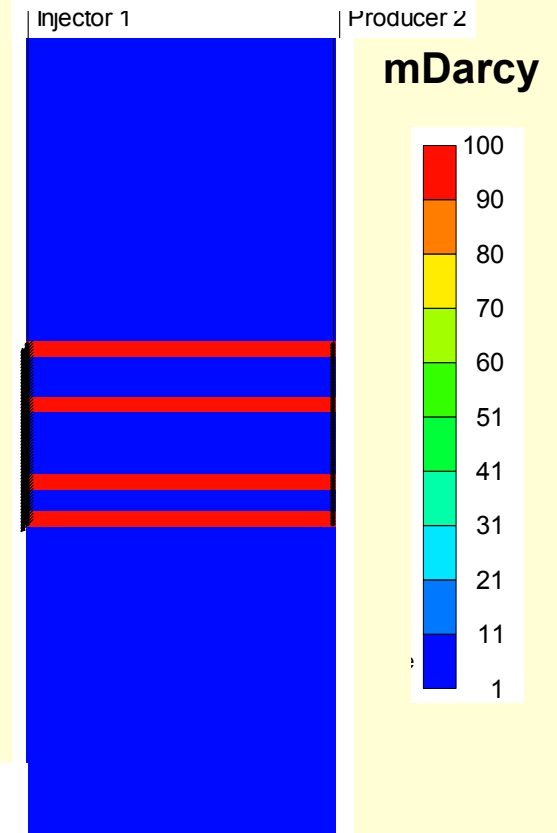


Reservoir Modeling: this scenario is for 5-spot pattern of production and injection at 1000 gpm per full well @ 500 m spacing (note: NO WATER CONSUMED!)

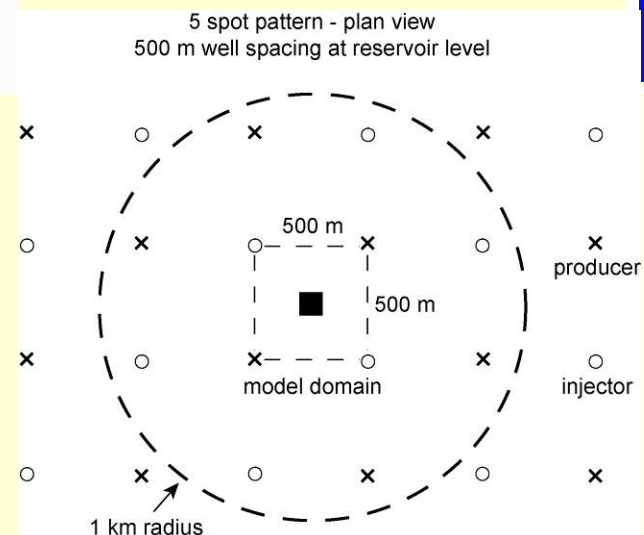


Four 25m zones of 100 mD (10 D - m) over 300 m of depth in 1 mD host rock at about 3 km depth; bedrock gradient = 37°C/km.

Top of model at ~ 2.2 km depth; average reservoir temperature initially 200°C, injection temperature 75°C

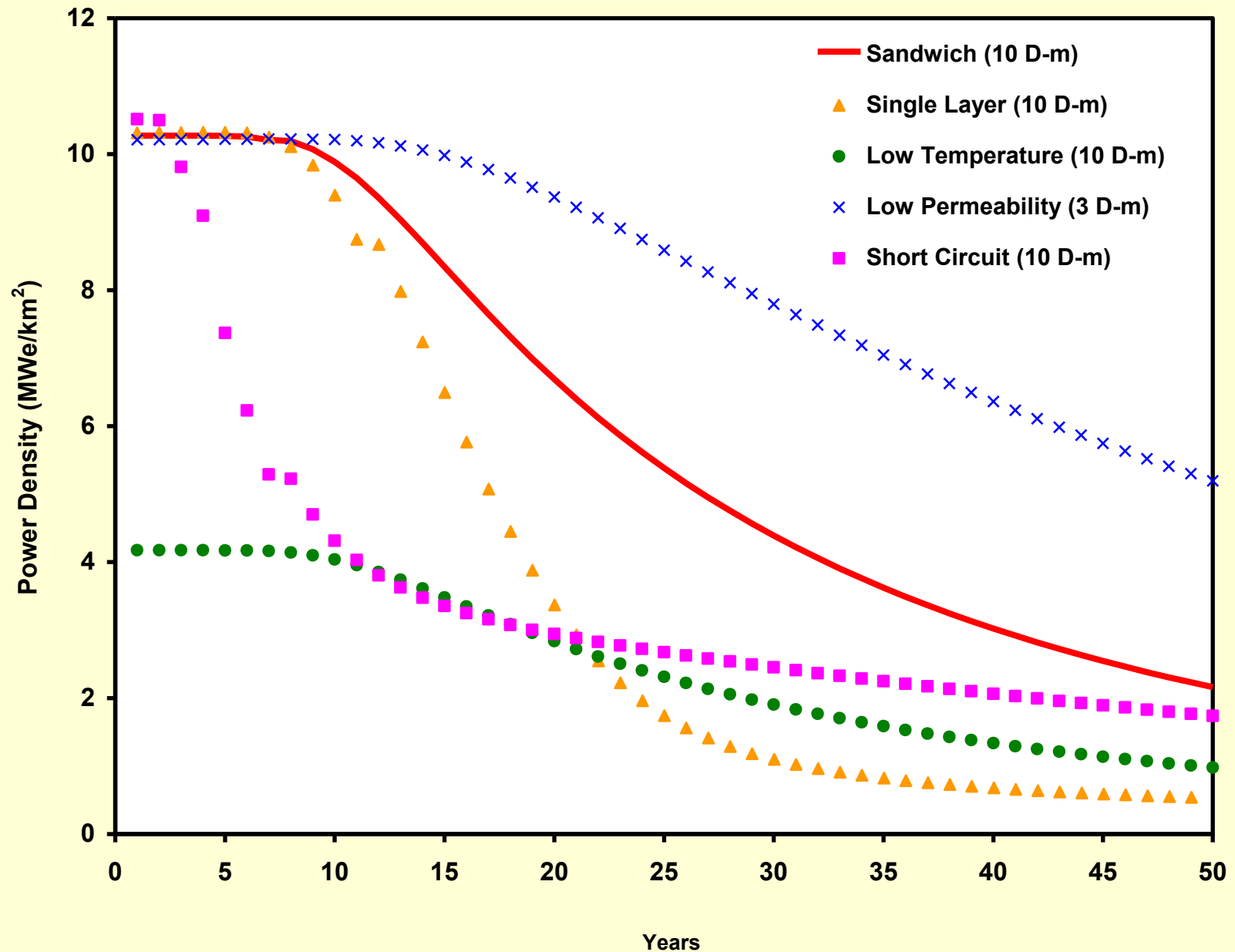


For this scenario, 6 pumped production wells and 6 injection wells are within a 1 km radius (3 km² area)

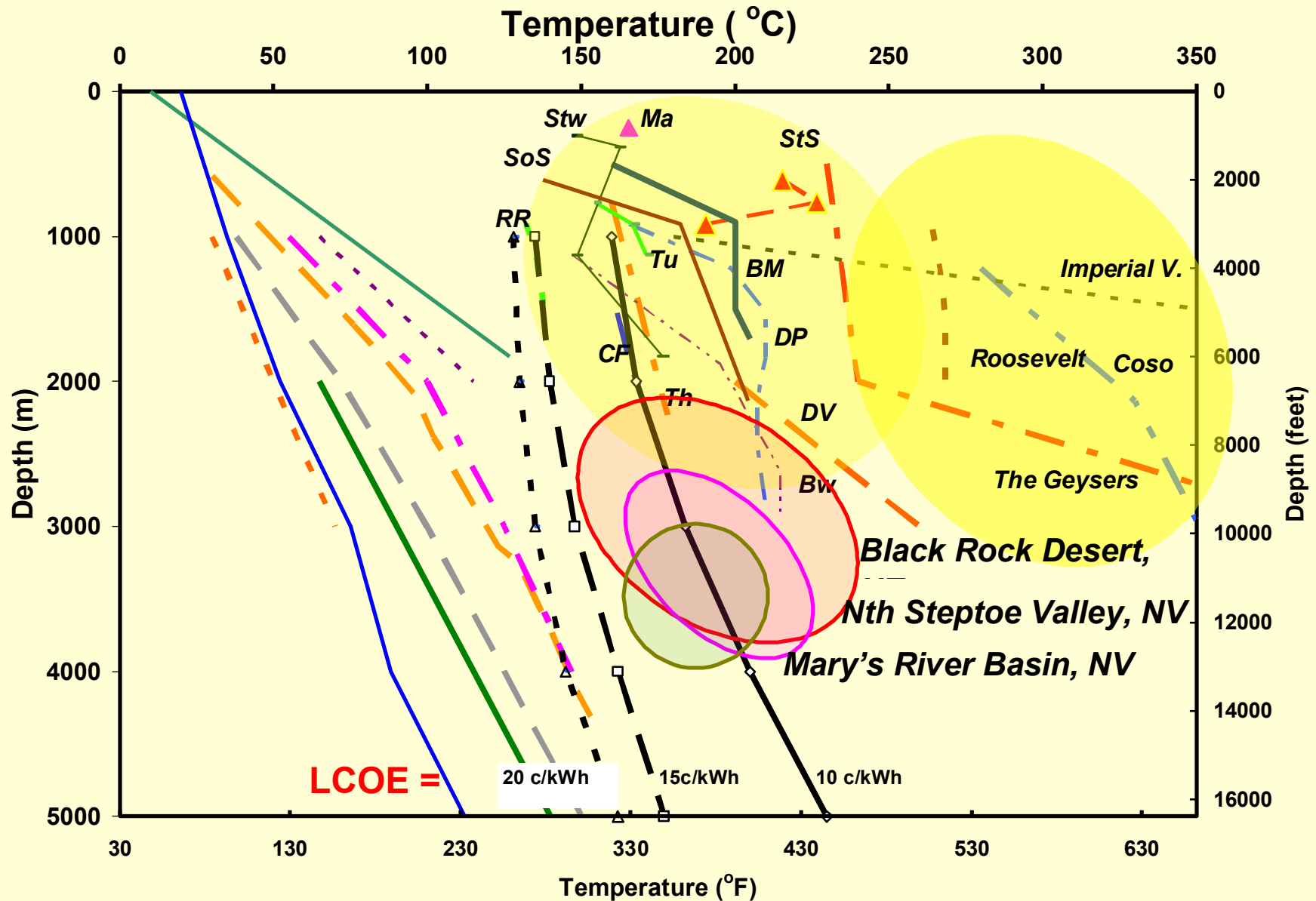


Reservoir Modeling Team, Roehner and Deo (Univ. of Utah)

Reservoir modeling shows even with poor reservoir characteristics, an average power density of 3 MWe/km² implies high heat flow basins have 100+ MWe potential



Economic Modeling – an LCOE of <10c/kWh is possible for stratigraphic reservoirs in “the Prize” zone. Reservoir temperatures in our three focus basins are highlighted – the target is reservoirs of ~ 200°C (400°F) at 3 – 4 km depth



Conclusions

- Growth in geothermal power developments has been slow compared to wind and solar over the last decade (~ 1%/year)
- Although technologies such as enhanced (or engineered) geothermal systems are being worked on, and the potential is massive, significant power developments seem to be at least a decade away
- Stratigraphic reservoirs beneath high heat flow basins such as those beneath the Great Basin of the Western U.S. should be the next major step in geothermal power developments:
 - the basins are large (hundreds of square km)
 - temperatures of ~ 200°C (400°F) exist at 3 – 4 km depth (10,000 – 13,000')
 - permeable stratigraphic targets exist in the Paleozoic basement beneath the basins
 - reservoir and economic modeling indicate hundred-MWe-scale developments with LCOEs of < 10c/kWh are achievable
 - The most attractive basins we have found so far are Black Rock Desert (UT) and Steptoe Valley (NV)
 - Developments would be pumped wells, air-cooled binary power plants, and no consumption of water; reservoir heat transfer is analogous to water flood in secondary oil recovery
 - New transmission infrastructure is planned traversing the Black Rock Desert and linking with southern California